Evaluation of the Performance of Broadband Networks and Short Period Arrays in Global Monitoring

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ABSTRACT

This study is a collaborative effort between the UC Berkeley Seismographic Station and the Lawrence Livermore National Laboratory to examine the performance of various seismographic systems in the regional monitoring of a Comprehensive Test Ban Treaty. Central California, with its abundant seismicity, regional broadband network (UCB BDSN), and dense short-period network (USGS NCSN) provides an ideal test-bed for the estimation of detection and location thresholds, source depth, and the seismic moment tensor of small events using sparse broadband network configurations. The objective is to investigate the importance of regional broadband stations in global monitoring. Together, the BDSN and NCSN networks provide the necessary data to construct a control catalog of very high quality event locations to a lower magnitude of approximately 1.8. We compare, against the control, catalogs obtained by inverting only BDSN data (both P only, and P and S waves), subsets of BDSN to test very sparse network configurations, as well as event detections and locations obtained from two regional short-period arrays located in Lajitas, TX and Pinedale, WY. In this manner we determine the detection and location threshold of each system and assess the resolving power of each. In particular, source depth resolution is investigated in the context of a traditional first motion location scheme, as well as the use of broadband waveforms recorded at regional distances. A component of this study will be the examination of path calibration to improve both source depth and seismic moment tensor determinations for small events recorded at regional distances. Improvements to the existing location algorithms will be examined to better constrain the BDSN and sparse network solutions. A goal of this research is to demonstrate how well a region may be monitored with a sparse broadband network given an optimal source-station geometry such as the case in central California. Hence this is a best case scenario. Another goal is to evaluate the performance of very sparse network configurations (using subsets of BDSN) such as will be the case in the monitoring of other regions.

Keywords: Detection, Location, Source Depth, Path Calibration

OBJECTIVE

The objectives of this study are related to better understanding the importance of broadband stations in global and regional monitoring. The primary objective is to investigate sparse broadband network and regional short-period array capabilities in the detection and location of seismic events in a region with very good control (Figure 1). One component of this study will provide an estimation of detection threshold for a best case scenario. The performance of the full compliment of BDSN stations, as well as subsets of stations to analyze the performance of very sparse configurations, will be examined. The performance of short-period arrays (TXAR and PDAR) in monitoring the same region are also compared. TXAR and PDAR are both located between 8° to 20° from central California (depending upon event location) and the analysis of these data will be representative of regional monitoring capabilities of these systems. The resolution of source depth from both traditional location techniques as well as full waveform techniques is also examined. Finally, path calibration to improve both source depth estimates and seismic moment tensor determinations for small events is investigated with the goal of developing procedures which may be ported to other regions of interest.

Research Plan and Preliminary Results

The research plan involves the construction of a number of event catalogs to assess the detection and location thresholds for various seismographic systems in the monitoring of central California seismicity. A control catalog of very high quality locations will be constructed for M>=3 events using BDSN P and S picks and the P picks from the NCSN network (Figure 1). The BDSN picks used in the control catalog are all human reviewed. The control catalog will be augmented with 1.8<M<3.0 events using only the NCSN phase picks. Test catalogs will be constructed from BDSN P only, BDSN P and S, and the Lajitas and Pinedale data set. We anticipate that the initial BDSN only locations will be rather poor depending upon event location and size, as discussed below. To improve the BDSN locations other information such as azimuth (obtained by vectoring the P-wave) will be incorporated in the location methodologies and compared against the control.

Although this project has just begun and we are still in the process of compiling the various catalogs, the following examples illustrate the type of information that we will use in the assessment of the performance of sparse broadband systems in regional monitoring. Figure 2 compares 8 solutions for a Mw4.0 event located near San Benito, CA (EVT_A, Figure 1). This particular earthquake was not reported in the GSETT-3 REB bulletin.

We compare the solutions in terms of origin time, magnitude, location and source depth. Solution 1 represents the control location obtained from hand timed P and S phases of the BDSN network and the automated P picks of the NCSN network. Readings which gave large residuals were culled from the phase file. Solution 2 is the location obtained from all of the available readings. In this case the two are very similar because the location of the event within both BDSN and NCSN provides a very good constraint on the location parameters. Solutions 3 and 4 are the culled and unculled BDSN P wave only inversions. Solutions 5 and 6 are the culled and unculled BDSN P and S wave inversions. Again in this case the culled inversions result in a relatively robust solutions and the unculled inversions show both the greatest uncertainty and mislocation. This implies that the inclusion of one or more bad picks in a sparse data set can lead to relatively large mislocations and location uncertainties. Solutions 7 and 8 are automated inversion results using BDSN P and NCSN, and BDSN P only, respectively. Comparing 3 and 8 reveals that the human reviewed picks give both lower mislocation error and generally lower uncertainties. For this particular event the individual locations all fall within a circle with a 10 km diameter. Source depth is reasonably well constrained by inversions 1, 2, 3, and 5.

Figure 3 compares 7 solutions for a Mw4.1 event located near Quincy, CA (EVT_B, Figure 1). This event was also not reported in the GSETT-3 REB. As in Figure 2 the solutions are compared in terms of event origin time, magnitude, location and source depth. The solution numbers represent the same inversions that were performed in Figure 2 with the exception that solution 7 represents the automated solution using only raw BDSN P picks. The two most striking differences between Figures 2 and 3 are the magnitude of the mislocation errors and that depth is relatively poorly constrained for the Quincy event. Both result from the lack of close stations. In fact for the P wave only calculations, since the closest broadband station is 74 km away, the algorithm we use does not attempt to solve for depth and it is set to 5 km. When S waves are included the algorithm attempts to solve for source depth, however the uncertainties can be large.

Figure 4a illustrates the automated moment tensor (see Pasyanos et al., 1995) results for the Quincy event using the three closest BDSN stations in the frequency band from 0.02 to 0.05 Hz. This result is for a best fit depth of 11 km. The Green's functions in this calculation are computed for depth intervals of 3 km and therefore the depth resolution remains relatively poor. It is possible to use short-period regional phases as source depth indicators (e.g. Dreger and Helmberger, 1991, 1993; Zhao and Helmberger, 1994). Phases such as sPmP and sSmS etc. are examples of depth indicators at regional distances. It is possible to find other depth sensitive phases such as the SP free surface defraction for example. As Figure 4b illustrates, the SP phase is observed on the radial and vertical components of displacement recorded at ORV (74 km SW). Figure 4b shows that this particular phase is strongly source depth dependent, and following the assumption that the velocity structure used to compute the Green's functions is a reasonable approximation, it is possible to fine tune the depth to between 9 to 10 km.

Conclusions and Future Plans

We have presented examples of the analysis that we intend to perform on 1993-present seismicity in central California. Our immediate plans are to compile the control and various test catalogs of past seismicity and to install the software necessary to update the catalogs with current seismicity. We have shown that sparse network solutions can have mislocations of several to tens of kilometers. It is anticipated that the very sparse calculations that will be performed will have initially poor results. We will therefore investigate modifications to our location routines to improve sparse network locations. One improvement which appears to be promising is the inclusion of azimuthal information contained in the P-wave. Source depth was also prone to large uncertainty, however utilizing secondary depth sensitive phases leads to improved source depth estimates. Whether or not the mislocation errors are acceptable depends upon the individual monitoring situations. The omission of both the Mw4.0 San Benito and Mw4.1 Quincy events from the GSETT-3 REB illustrates the need for regional broadband stations particularly in the monitoring of small events.

In conclusion, the results of this study are expected to provide important bounds on how well a region may be monitored with a relatively sparse broadband network. That is we will establish minimum detection and location thresholds for solutions using 1) the full compliment of BDSN stations, 2) very sparse BDSN network configurations, and 3) the Lajitas and Pinedale arrays.

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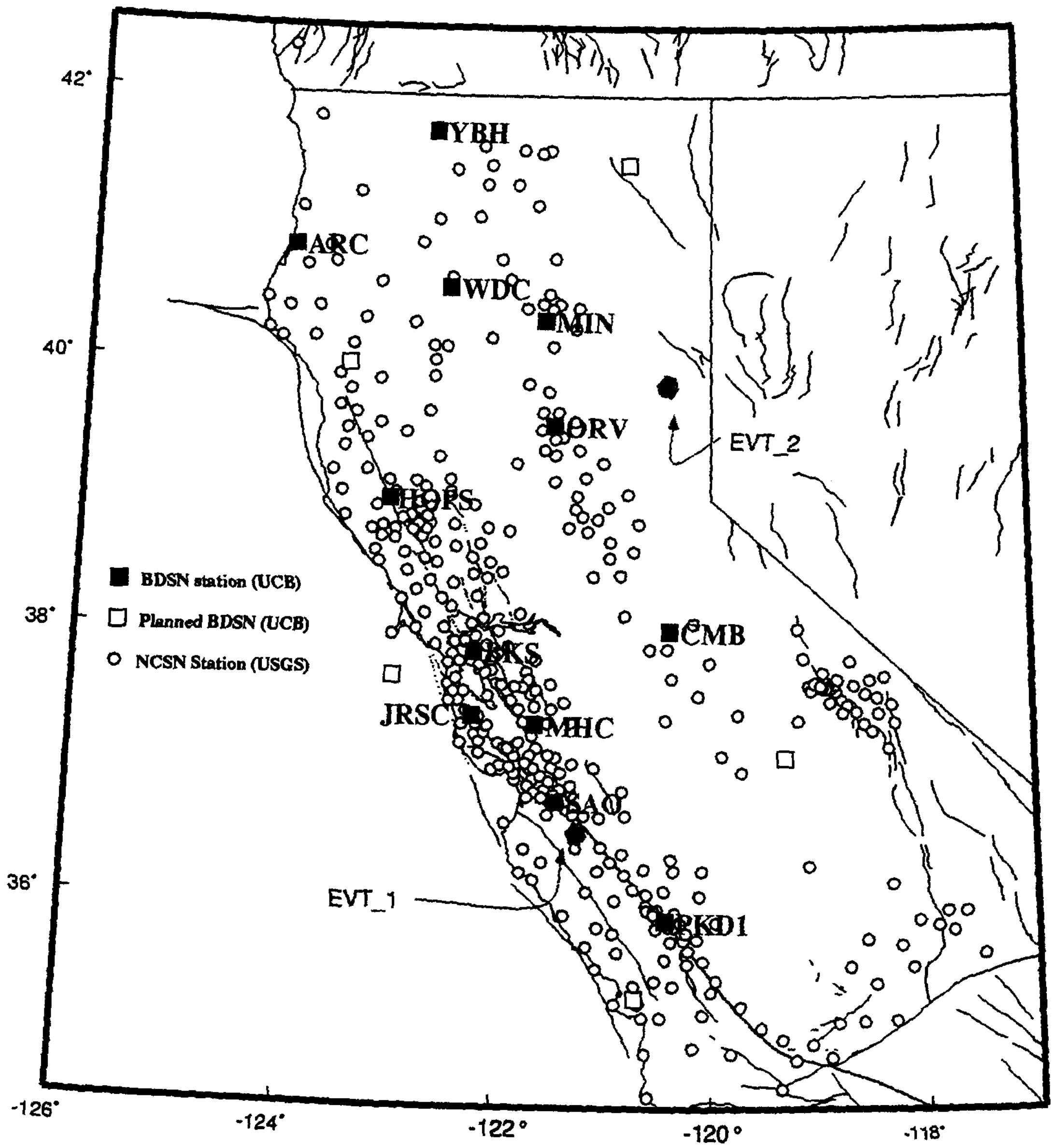

Figure 1. Map showing the locations of BDSN and NCSN stations. Two events discussed in detail in the text are labeled.

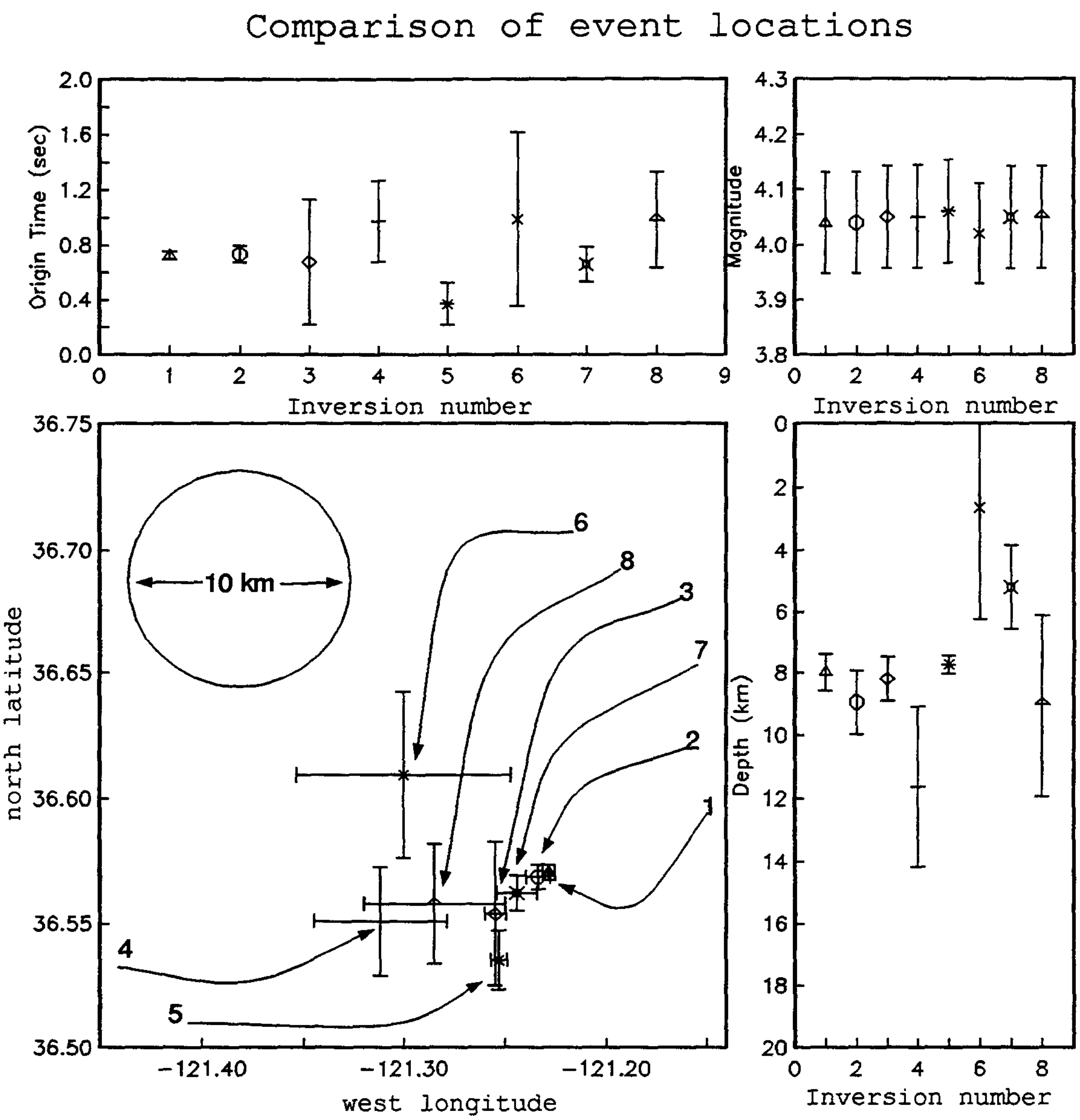

Figure 2. Comparison of event origin time (s), magnitude (ML), epicentral location and source depth for a number of different inversions. Inversion 1 refers to the control location obtained from human reviewed BDSN P and S and NCSN P phase picks. Stations with large residuals have been culled. Inversion 2 is the same as 1 except all of the data was used. Inversions 3 and 4 are BDSN P only inversions with large residual stations removed, and all of the available stations included, respectively. Inversions 5 and 6 are the same as 3 and 4 except that S waves were included. Inversions 7 and 8 are automated REDI (Gee et al., 1995) solutions using BDSN and NCSN autopicks.

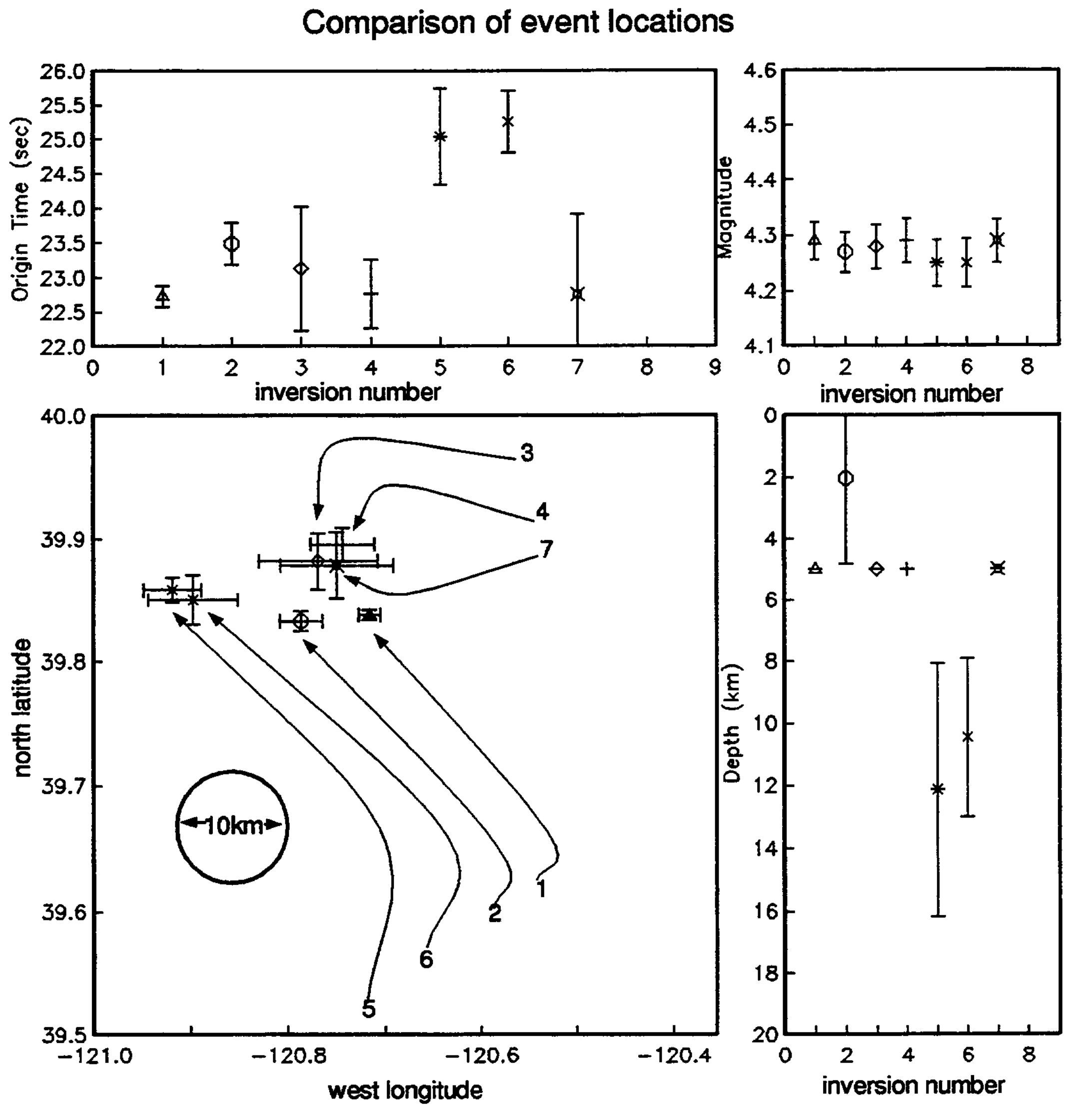

Figure 3. Comparison of event origin time (s), magnitude (ML), epicentral location and source depth for a number of different inversions. Inversion 1 refers to the control location obtained from human reviewed BDSN P and S and NCSN P phase picks. Stations with large residuals have been culled. Inversion 2 is the same as 1 except all of the data was used. Inversions 3 and 4 are BDSN P only inversions with large residual stations removed, and all of the available stations included, respectively. Inversions 5 and 6 are the same as 3 and 4 except that S waves were included. Inversion 7 is an automated REDI (Gee et al., 1995) solution using BDSN and NCSN autopicks.

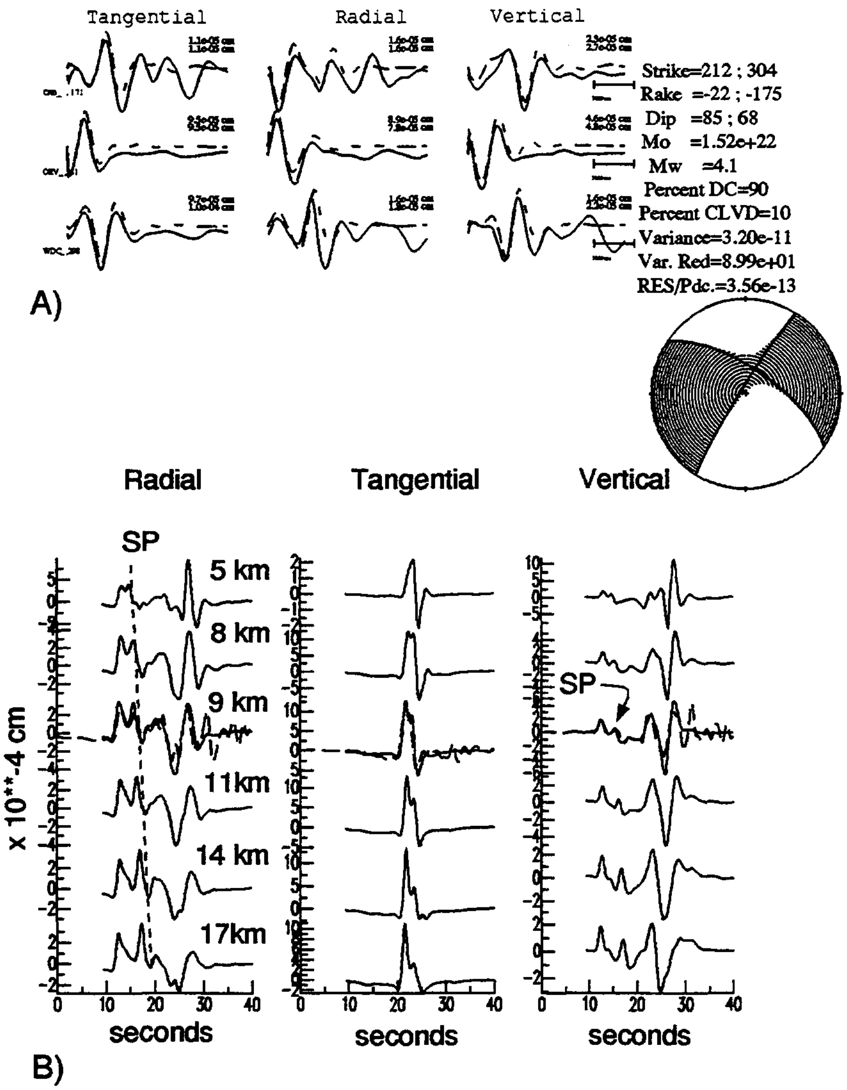

Figure 4. a) Moment tensor inversion of three-component displacement data (0.02 to 0.05 Hz) recorded at the three closest stations. The data are solid traces and the synthetics are dashed. The best fitting source depth was 11 km. b) Comparison of broadband (0.01 to 0.5 Hz) displacement synthetics (solid) with data recorded at the ORV station (dashed). The dashed line highlights the moveout of the SP phase.